$K^0 \leftrightarrow \bar{K}^0$ transitions in matter

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The predicted time asymmetry between the rates of $K^0 \to \bar{K}^0$ and $\bar{K}^0 \to K^0$ transitions is shown to remain the same whether the kaons propagate in ordinary matter or in vacuum.

Failure of T invariance, viz., reciprocity, is expected[1] on the basis of the observed CP noninvariance[2] in neutral-kaon decays and the theoretical premise[3,4] of TCP invariance, but is yet to be observed in any phenomenon. The CP noninvariance reported in neutral-kaon decays is attributable entirely to a small admixture of the $CP=+1$ component in the long-lived neutral-kaon state, which is almost a $CP=-1$ eigenstate. As long as this is the case, the only T-noninvariant effect which can be definitely predicted[1] is a difference in the rates of $K^0 \to \bar{K}^0$ and $\bar{K}^0 \to K^0$ transitions. We shall show below that the predicted time asymmetry remains the same whether the kaons propagate in a vacuum[1] or in matter likely to be encountered in terrestrial laboratories. This may have some relevance for proposed[5,6] experimental tests of the effect.

In a material medium, the coherent forward propagation of a neutral-kaon beam is described by adding to the quasi-Hamiltonian Λ, which describes the time evolution of an arbitrary free neutral-kaon state, an optical potential representing the effective interaction of kaons with the medium. For a "dilute" medium, the additional term is given by[7]

$$\Lambda_{\text{med}} = -2\pi m_k{}^{-1} \begin{bmatrix} \sum_j f_j & 0 \\ 0 & \sum_j \bar{f}_j \end{bmatrix} , \tag{1}$$

where f_j and $\bar{f}_j$ represent the forward-scattering amplitudes for K^0 and $\bar{K}^0$, respectively, from a scatterer j, and the summation extends over all the scatterers in a unit volume. In principle, there could be off-diagonal entries in (1) caused by $\Delta S=2$ interactions but, according to a well-known argument,[8] these are extremely small, of order 10^{-12} relative to the diagonal terms and totally negligible in the present context. The addition of a term such as (1), which distinguishes between K^0 and $\bar{K}^0$, to the quasi-Hamiltonian is formally equivalent to the introduction of an effective TCP-noninvariant interaction. Since Ref. 1 already considered the general case in which TCP invariance is *not* assumed, we can directly take over the result obtained there for the time asymmetry:

$$\mathscr{A}_T \equiv \frac{P_{K\bar{K}}(\tau) - P_{\bar{K}K}(\tau)}{P_{K\bar{K}}(\tau) + P_{\bar{K}K}(\tau)} = \frac{2\sin\sigma\cos\delta}{\cos^2\delta + \sin^2\sigma} , \tag{2}$$

where the parameters $\sigma = \pi/2 - (\alpha_S + \alpha_L)$ and $\delta = \alpha_L - \alpha_S$ are measures of T noninvariance and TCP noninvariance, respectively. The mixing angles α_S and α_L are now to be interpreted as the values corresponding to the eigenstates of the quasi-Hamiltonian *including* the extra term (1); we have changed the subscripts 1,2 of Ref. 1 to S,L to conform to the currently accepted notation.

The essential remark of this note is the observation that the ratio of the transformation rates $P_{K\bar{K}}(\tau)$ and $P_{\bar{K}K}(\tau)$, given by Eqs. (9a) and (9b) of Ref. 1, depends[9] only on the magnitude of the ratio $\Lambda_{\bar{K}K}/\Lambda_{K\bar{K}}$, which is unaffected by the addition of a term such as (1) which has no off-diagonal elements. Consequently, the interposition of any material substance of normal density between the point of production and the point of detection of a neutral kaon will not affect the predicted time asymmetry,

$$\mathscr{A}_T \cong 2\sigma , \tag{3}$$

to lowest order in the CP-violation parameters σ and δ which are known to be small. Under the hypothesis of TCP invariance (and ignoring possible small $\Delta S = -\Delta Q$ corrections), σ is the leptonic charge asymmetry in K_L decays; hence, the corresponding predicted value[10] of $\mathscr{A}_T$ is $(6.60 \pm 0.24) \times 10^{-3}$.

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